LA-UR- 03-7229

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Title: From Basic Research to Homeland Security : Muon Radiography and Large-Area Detectors

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Submitted to: Institute for Nuclear and Particle Astrophysics and Cosmology meeting, San Diego, October 5

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ABSTRACT

From Basic Research to Homeland Security : Muon Radiography and Large-Area Detectors

William C. Priedhorsky and Richard C. Schirato

Talk at meeting of Institute for Nuclear and Particle Astrophysics and Cosmology
San Diego, CA 3 October 2003

There are a number of connections between detector technology as developed for nuclear and particle astrophysics, and detection needs for homeland security. We set out two of them. We begin by discussing the basic detection requirements, and the emissions from uranium and plutonium. One way to detect the neutron flux is to develop a very large neutron detector, using technology developed for neutrino physics. Another way to detect dense, high-Z material is by its scattering of natural, cosmic-ray neutrinos, which are present all the time. We present concepts and simulations for the former, and experimental results and simulations for the latter.

From Basic Research to Homeland Security : Muon Radiography and Large-Area Detectors

October 3-5, 2003
INPAC meeting, San Diego

William Priedhorsky and Richard Schirato
Los Alamos National Laboratory

on behalf of the muon radiography team:
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and the VLAND/neutrino team:
Martin Cooper, Gerry Garvey, Bill Louis, Shawn McKenney, Geoff Mills, Dick Mischke, Joel Moss, Richard Schirato, Richard Van de Water, Nate Walbridge, Hywel White;
UNM: Doug Fields + students

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Homeland Security Needs

- Detection of Special Nuclear Materials (SNM) and nuclear WMD's
- Detection of Radiation Dispersal Devices (RDD's) or illicit radioisotopes
- Cargo/vehicle inspection for other threats, e.g. chemical explosives, drugs, etc.

Signatures: Spontaneous Fission

Nuclide	Specific Intensity [n/(g-s)]
^{235}U	0.0003
^{238}U	0.0136
^{238}Pu	2590.
^{239}Pu	0.022
^{240}Pu	1020.
^{241}Pu	0.05
^{242}Pu	1720.
^{237}Np	0.0001

Implication: U doesn't really emit neutrons, and the few percent of ^{240}Pu in reactor-produced material is dominant

Solution: Induce fissions with neutrons or gammas

Signatures: Gamma emission

$$^{239}Pu \xrightarrow{24{,}000\ y} {}^{235}U^* + \alpha$$

Relatively complex decay scheme; major gamma rays:

129.28 keV Intensity 140,000 γ /(g-s)

413.69 keV Intensity 34,000 γ /(g-s)

$$^{235}U \xrightarrow{710{,}000{,}000\ y} {}^{231}Th^* + \alpha$$

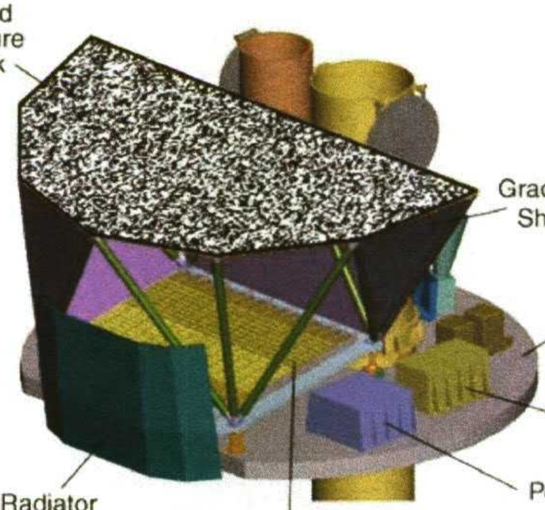
Much simpler decay scheme; major gamma ray:

185.72 keV Intensity 43,000 γ /(g-s)

Technology flow: "Homeland Security" to Basic Science

- **DOD and DOE have historically funded detector research which has found applications in Basic Science**
  - e.g. organic and inorganic scintillators, light detectors, Monte Carlo simulations, etc.
- **Recent Example:**
  - CdZnTe room temperature gamma/X-ray detectors

Burst Alert Telescope on SWIFT Mission



Drawing credit TBD

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Technology flow: Basic Science to “Homeland Security”

Possibilities from INPAC-related research include:

- Large area, efficient neutron and gamma detectors
- Cosmic ray muon radiography/interrogation
- Other detector technologies discussed at this meeting…

LANSCE Radiation Detection Portal

- 40 year-old technology
- Facility-specific

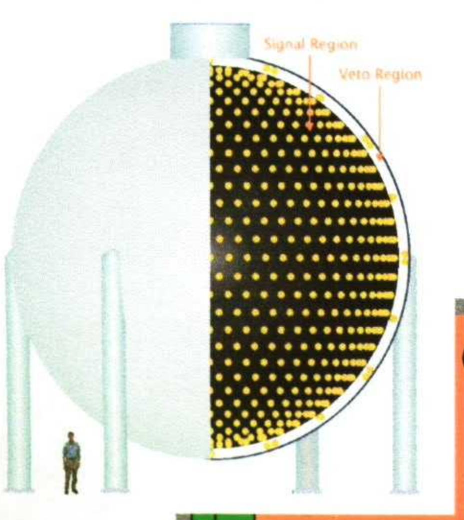
- solid plastic scintillators for γ detection (Compton)
- ^{3}He proportional counters for neutron detection
- hand-held monitors (NaI) for cargo searches

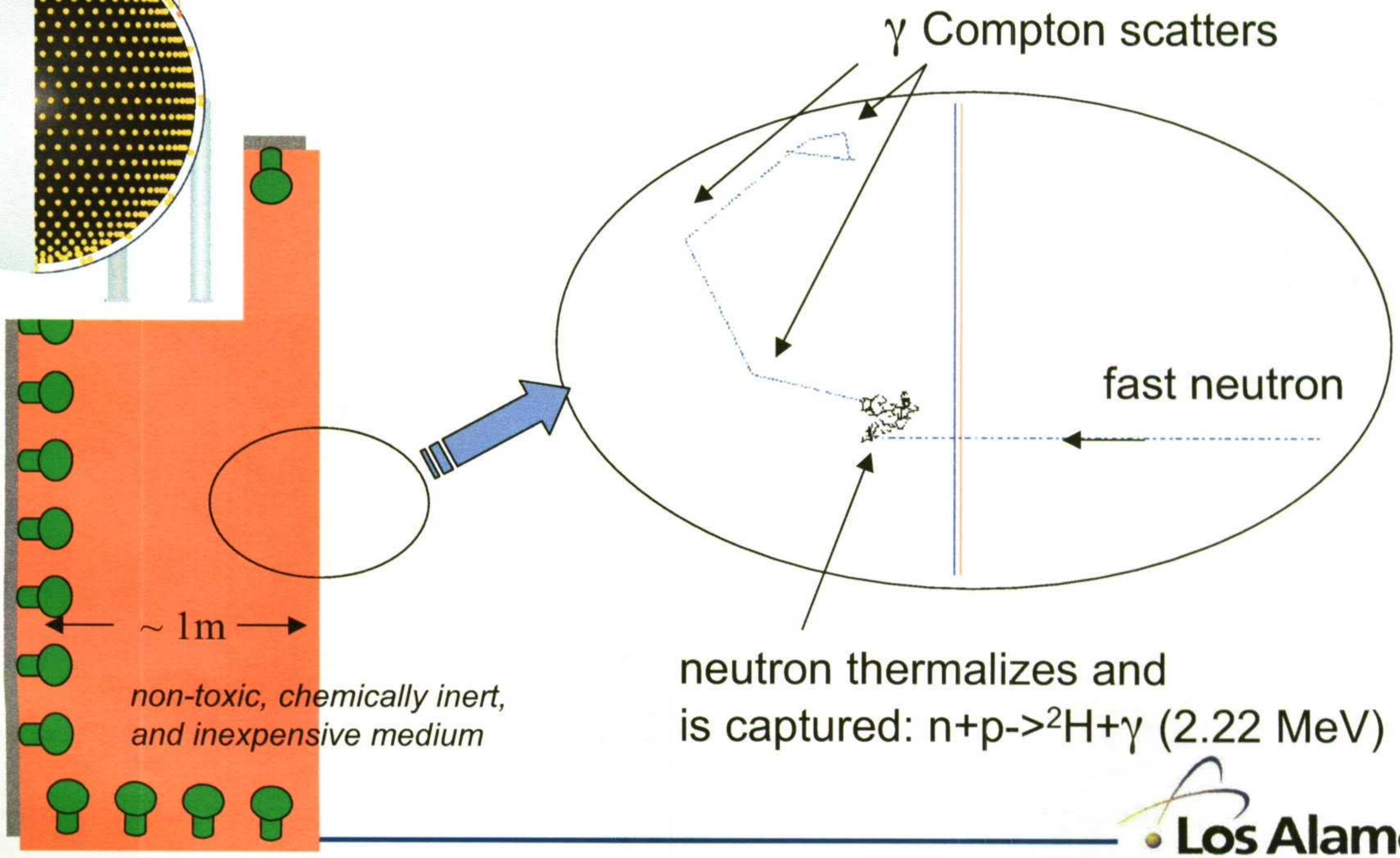
2 x 6”x31”x1.5” plastic scintillators
2 x 2”x40” moderated ^{3}He prop. counters

Very Large Area Neutron Detector- VLAND

Antineutrino technology applied to large-area neutron detection origins: LSND, miniBoone (LANL P-25 & UNM)

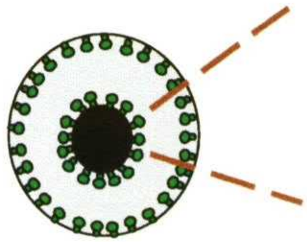
MiniBooNE Detector

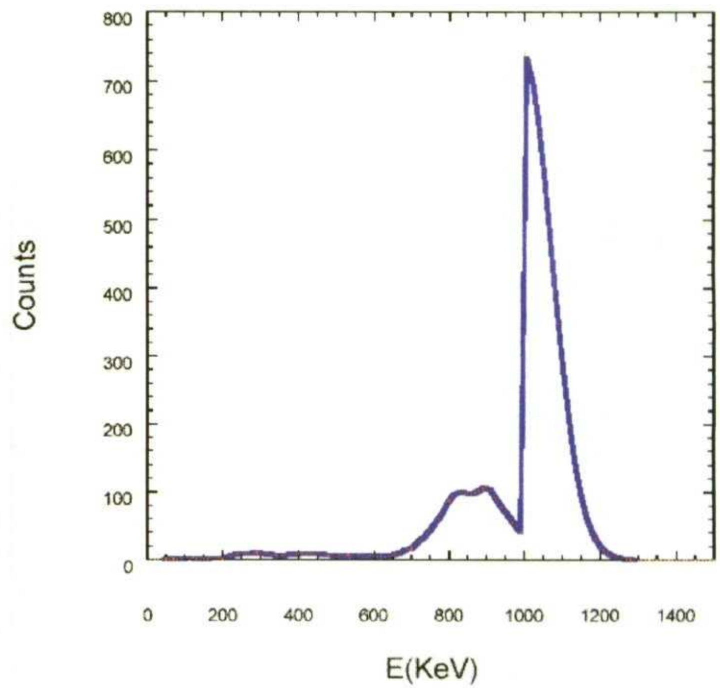




VLAND as a full-energy gamma ray detector

- Full energy containment: modest isotopic sensitivity [15%/√E (MeV)] unlike current plastic scintillator portal monitors
- better resolution possible
  KAMLAND: 7.5%/√E
- directional sensitivity



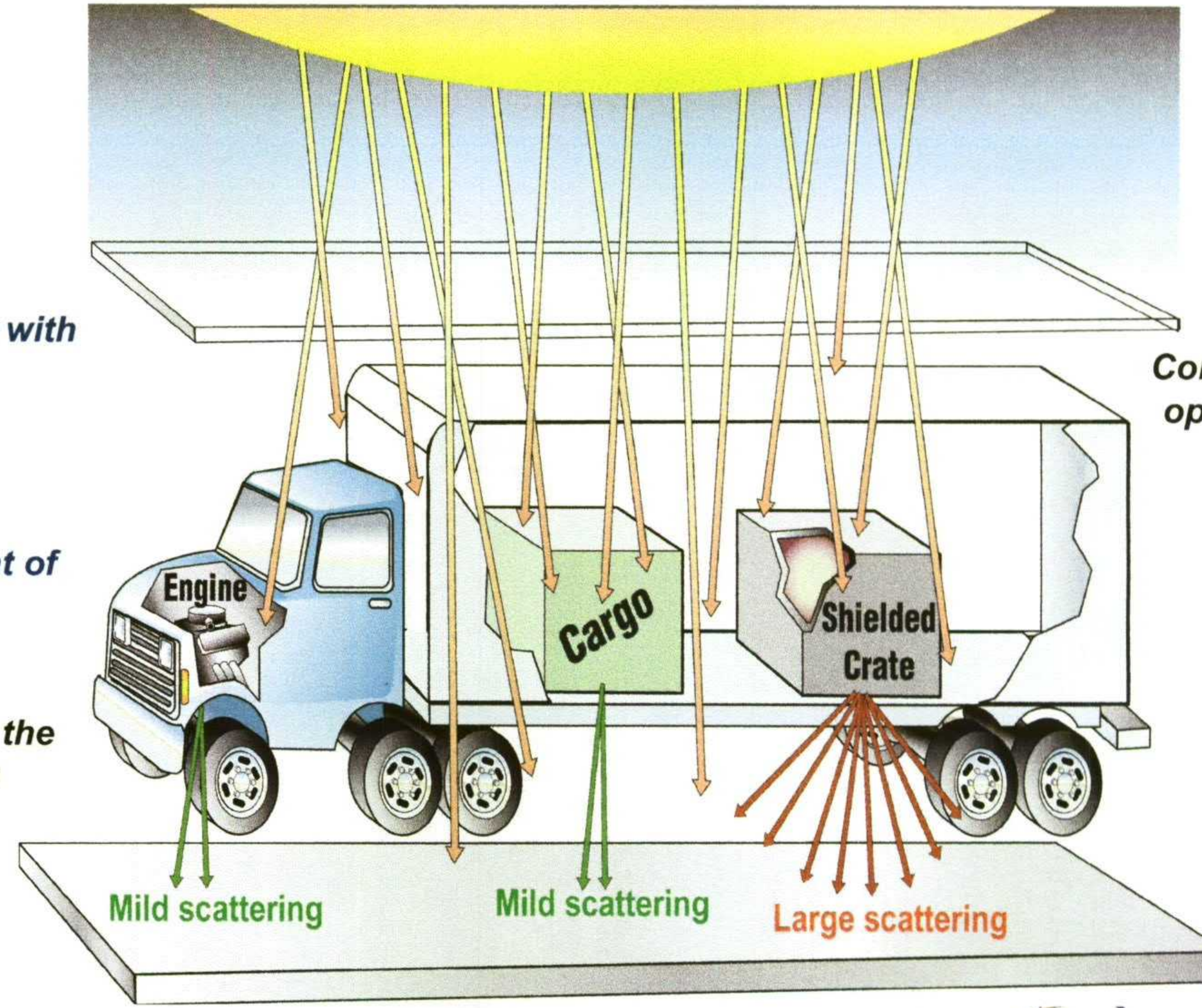


Zero-dose radiography

Objective:
penetrating radiography with no artificial dose

Application:
Prevent illicit movement of nuclear materials

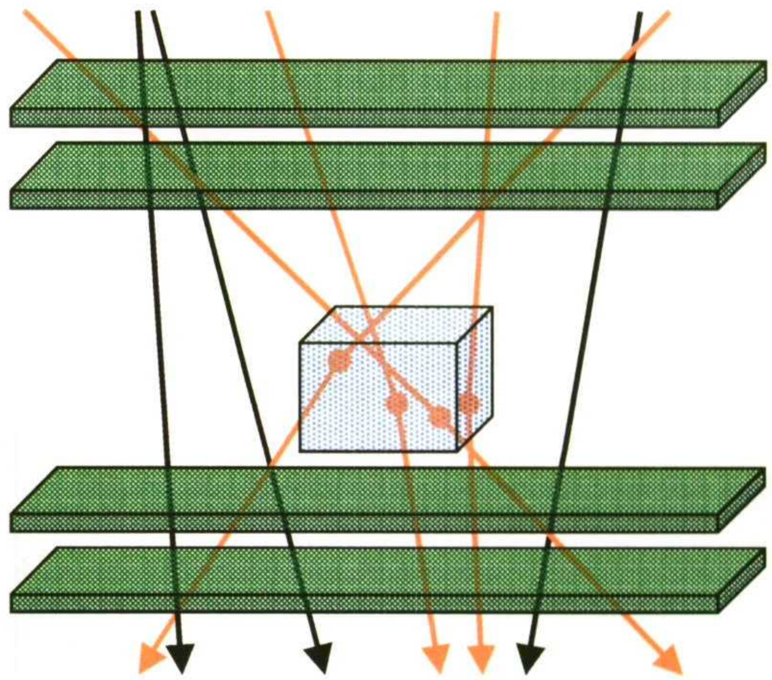
The heavier the shield, the easier the detection



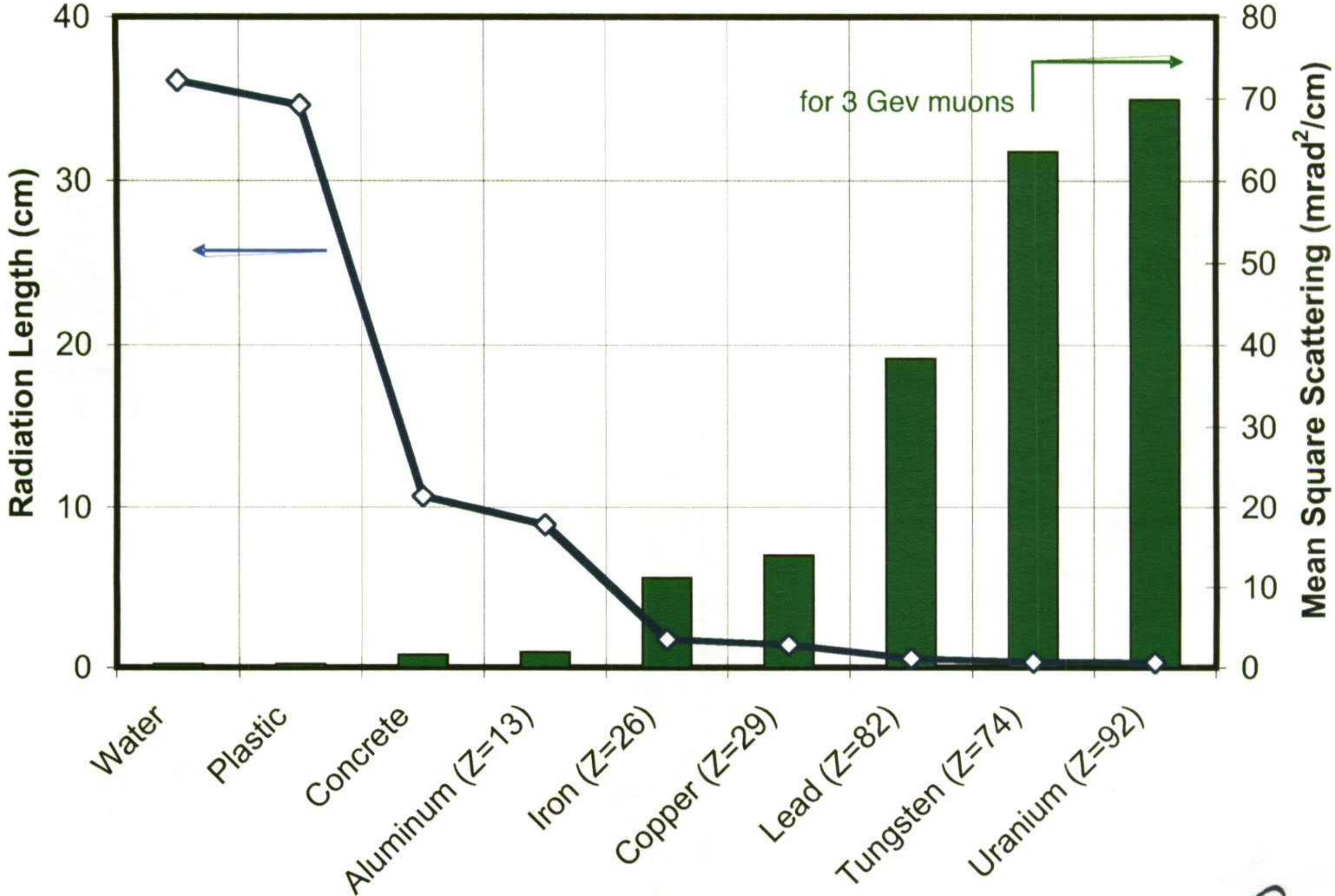
Concept of operation

Basic Concept of Muon Radiography

- Track <u>individual</u> muons (possible due to modest event rate).
- Track muons <u>into</u> and <u>out of</u> an object volume.
- Determine scattering angle of each muon.
- Infer material density within volume from data provided by many muons.
- New tomographic reconstruction algorithms are required.



Scattering is Material Dependent



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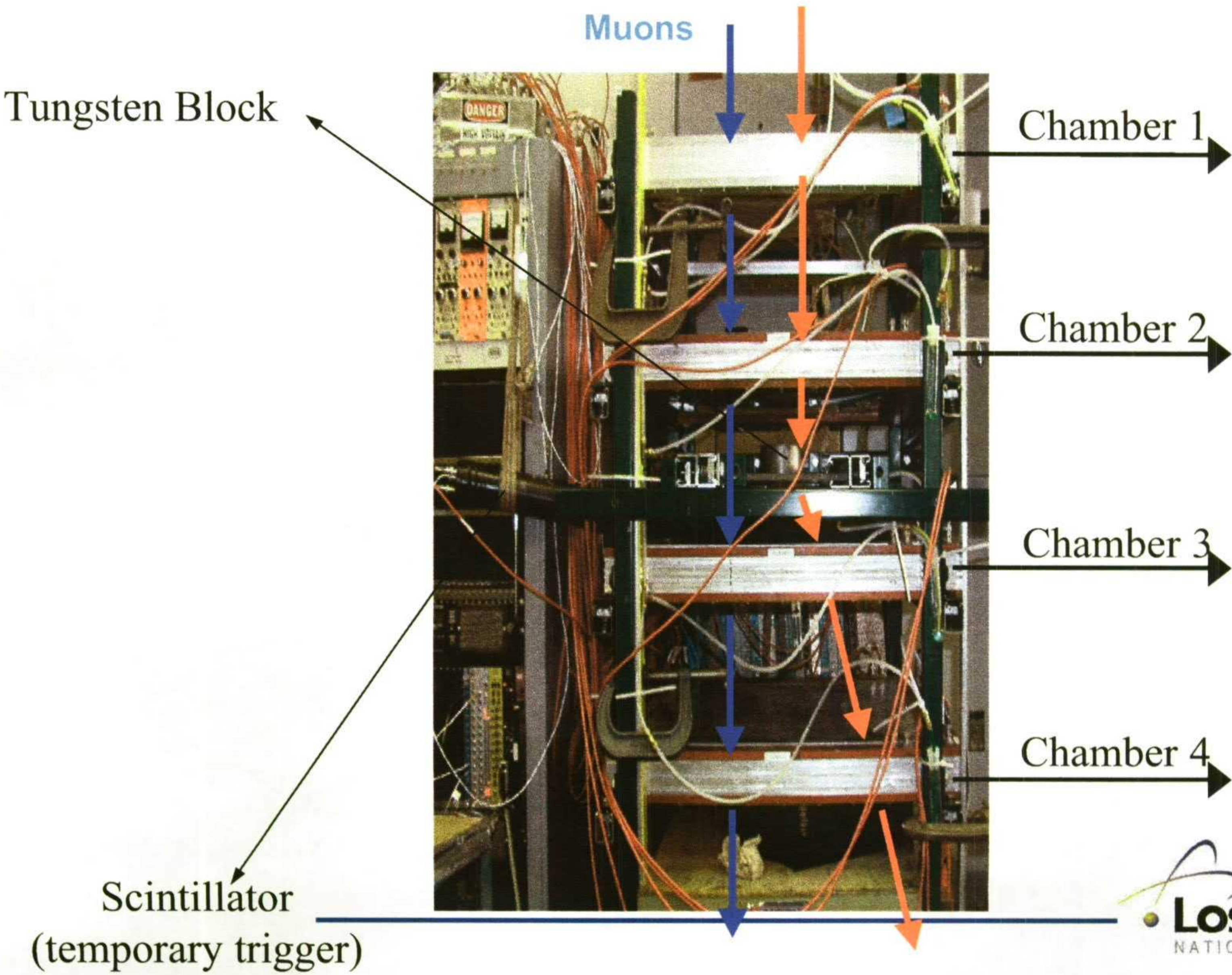
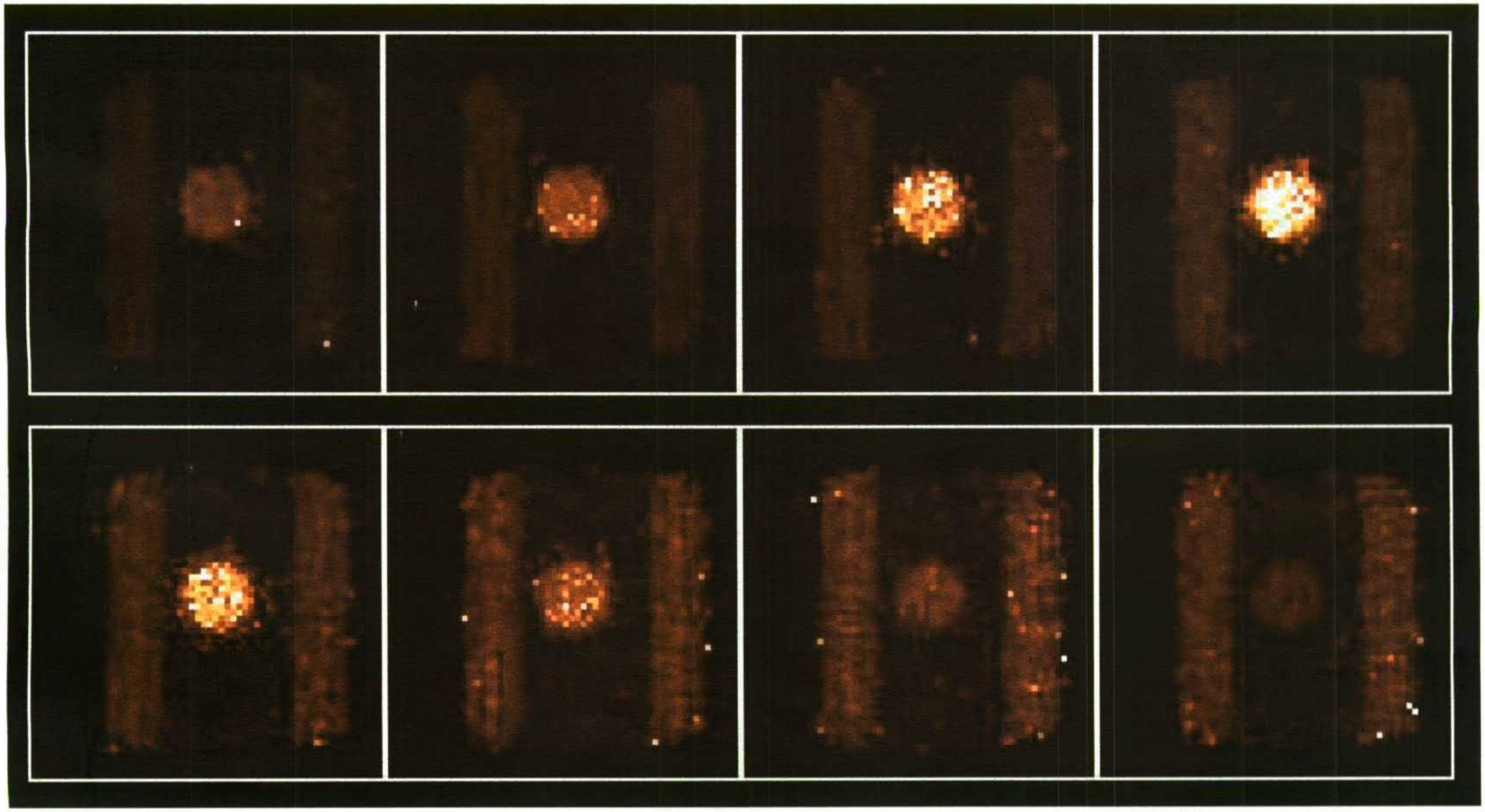
Prototype instrument



Slices through reconstructed volume



Experiment/Simulation Comparison

Experiment

Simulation

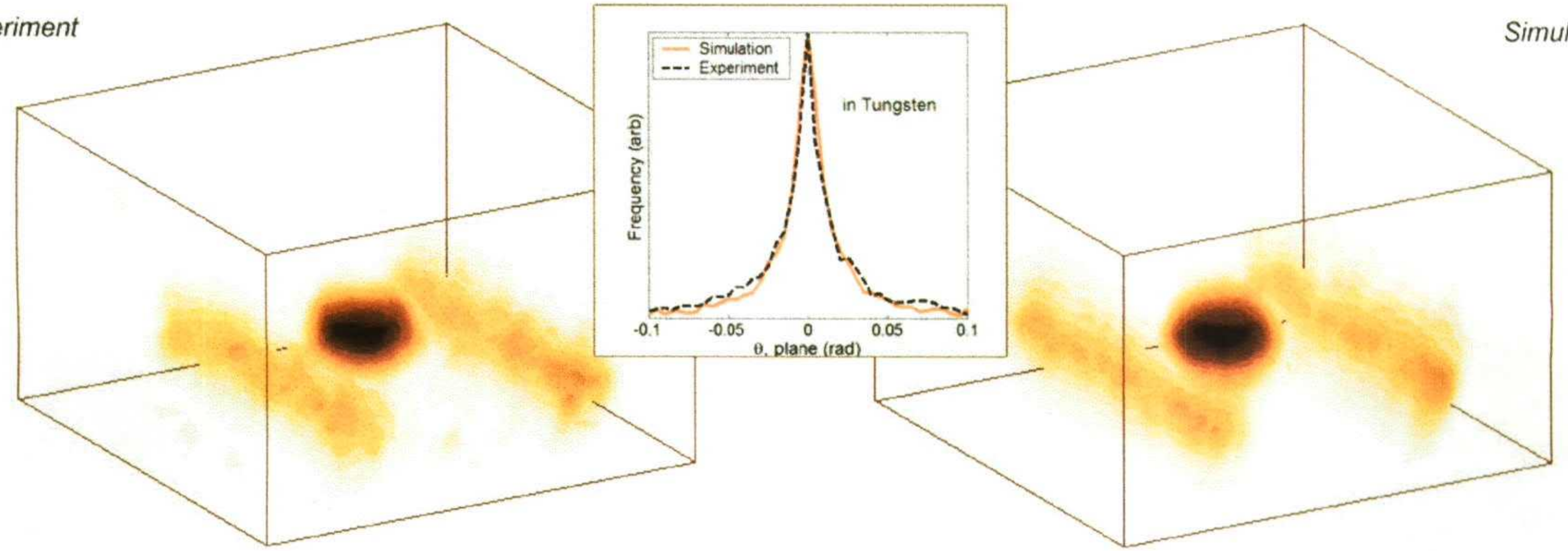


Image of a 5 cm high, 10 cm diameter tungsten block, and steel supporting struts, equivalent exposure 30 minutes

Simulation validated in this experiment, shows promise of nuclear material detection

Nature, 20 March 2003

Visibility in the press:

http://www.nature.com/nsu/030317/030317-7.html

http://news.bbc.co.uk/2/hi/science/nature/2868041.stm

http://www.guardian.co.uk/uslatest/story/0,1282,-2492519,00.html

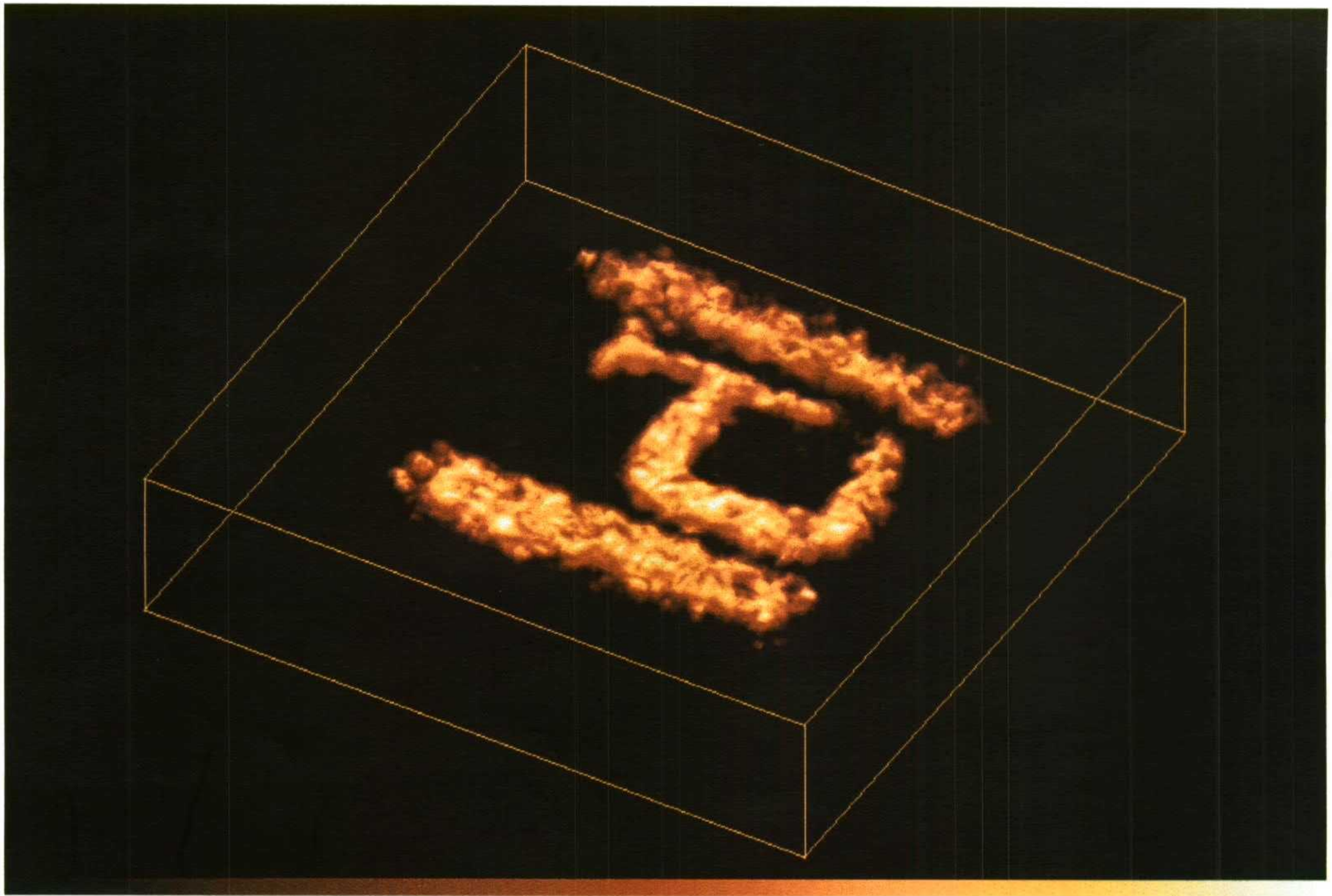
http://www.space.com/businesstechnology/technology/nuclear_detection_030319.html

http://www.physicsweb.org/article/news/7/3/11

http://news.nationalgeographic.com/news/2003/03/0319_030319_cosmicrays.html

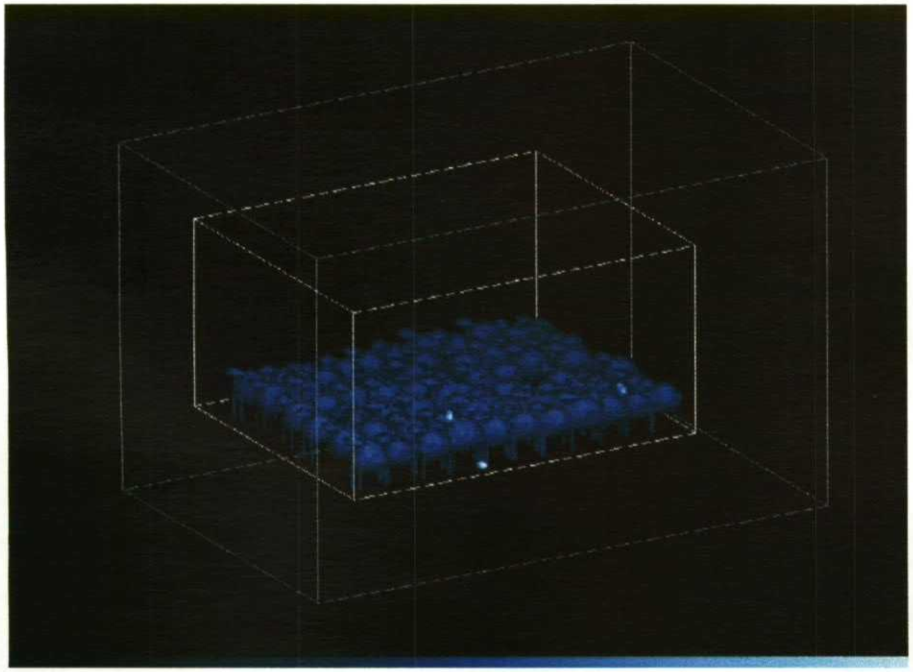
http://www.newscientist.com/news/news.jsp?id=ns99993526

Clamp in 3D

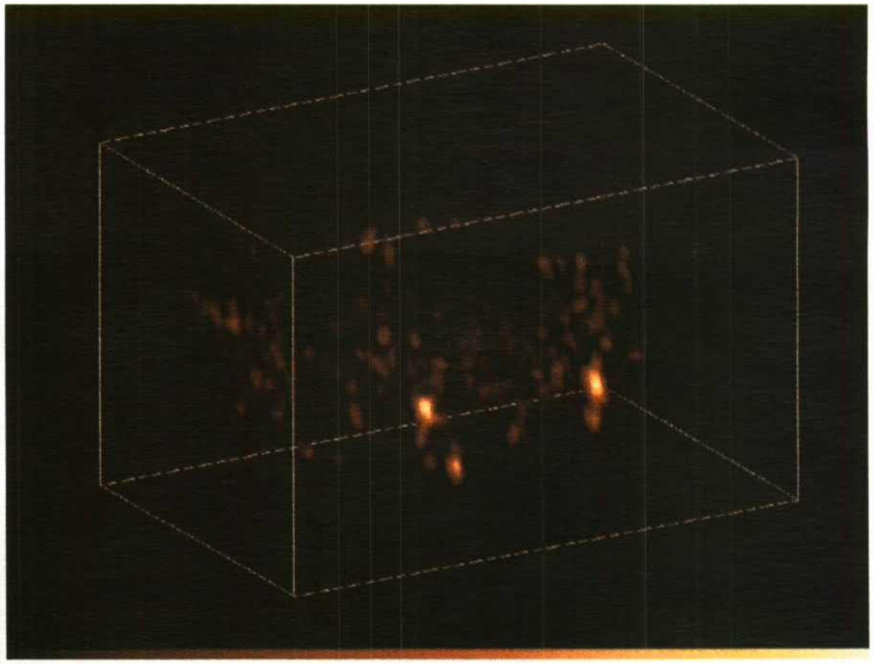


Perspective view

Uranium objects in a shipping container



OBJECTS
2.4 m x 2.4 m x 6 m container
3 mm steel wall
9 cm x 9 cm x 12 cm uranium "pigs"
(60 cm)³ water "sheep"



SIMULATED RADIOGRAPH
1 minute exposure
90% detection probability
>>6 sigma rejection of false alarms
"point of closest approach" reconstruction

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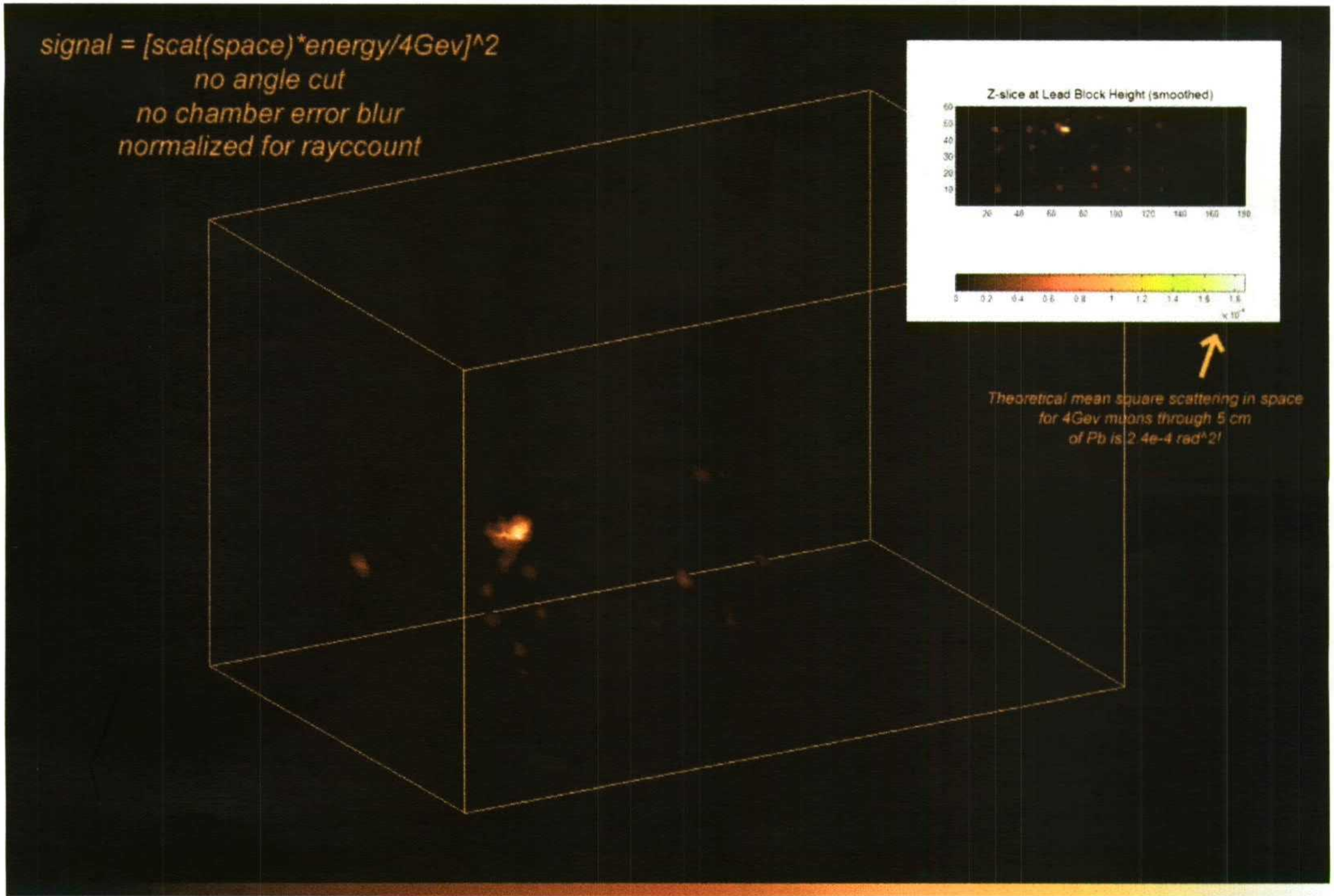
Car batteries vs. solid lead block



1 solid lead block (same size) in a load of 29 car batteries

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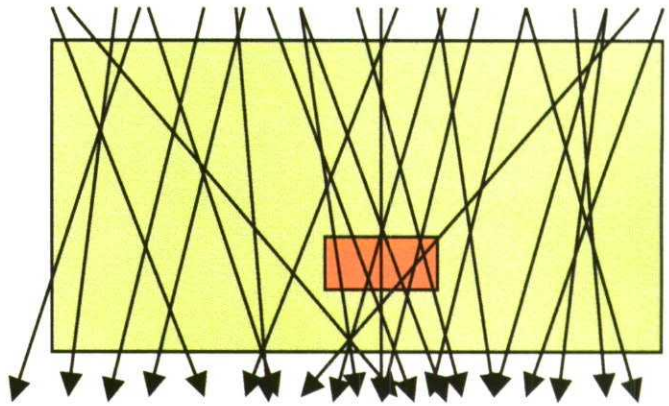
Clutter Rejection: Ray Crossing Algorithm

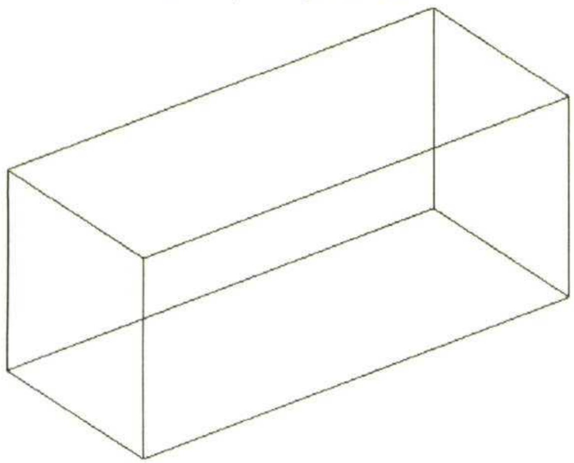
Apply a bend angle cut, keep only high bending rays

Apply an approach cut, keep only rays which approach one another closely.

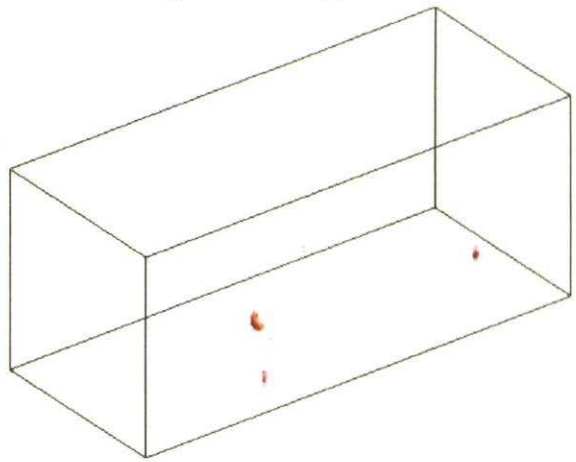
Create 3-D histogram of approach locations.



Sheep only, 30 sec



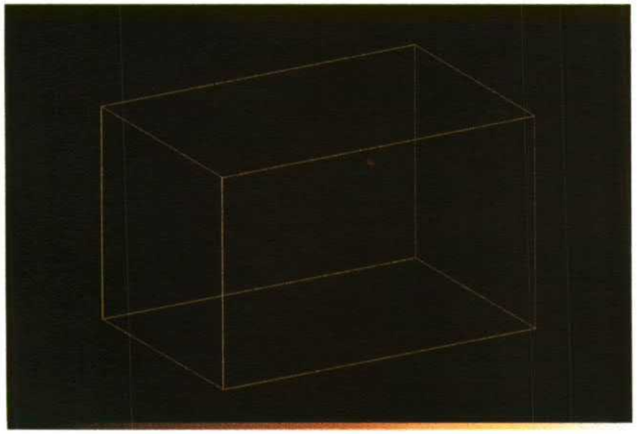
Pigs in Sheep, 30 sec

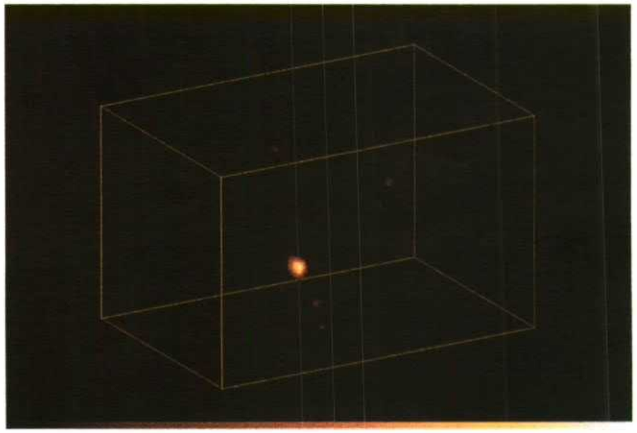


A Scene with more Clutter

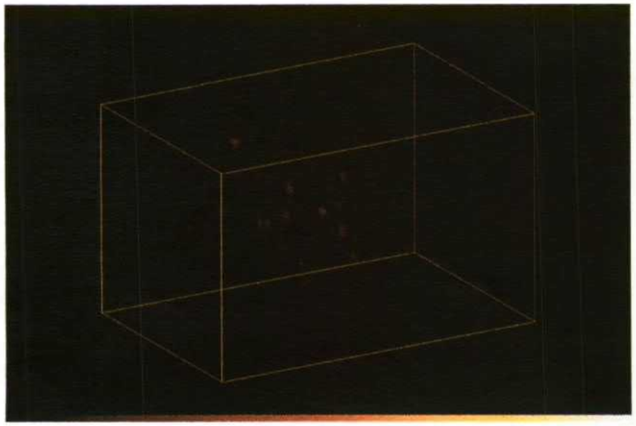
No contraband | With 3 pigs

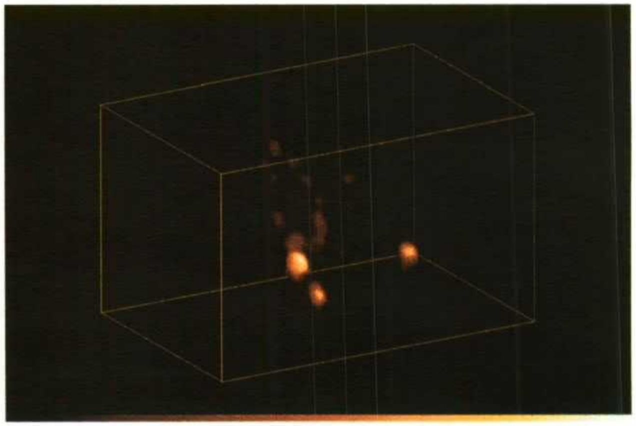
30 second exposure





120 second exposure





10 tons of distributed iron filling the container

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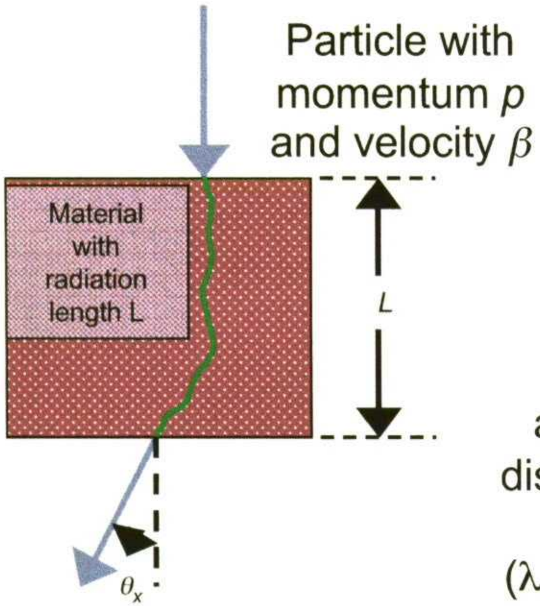
Backup slides

Physics of interaction: multiple scattering



Scattering distribution is approximately Gaussian

$$\frac{dN}{d\theta_x} = \frac{1}{\sqrt{2\pi}\theta_0} e^{-\frac{\theta_x^2}{2\theta_0^2}}$$

and the width of the distribution is related to the material (λ is a radiation length)

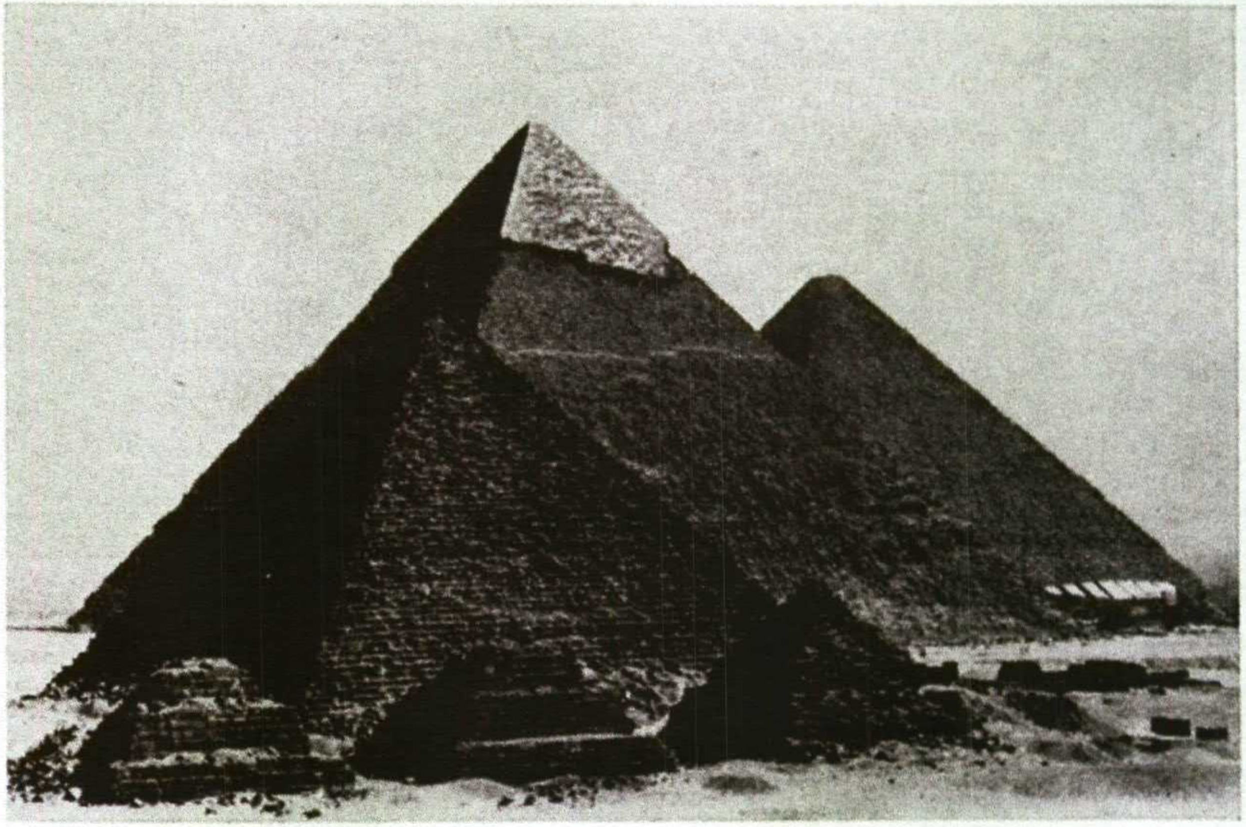
$$\theta_0 = \frac{13.5}{p\beta}\sqrt{\frac{L}{\lambda}}$$

Scattered particles carry information from which material may be identified.

Material	λ , cm	θ_0, mrad*
Water	36	2.3
Iron	1.76	11.1
Lead	.56	20.1
*10 cm of material, 3 Gev muons		

A previous target

Fig. 1 (top right). The pyramids at Giza. From left to right, the Third Pyramid of Mycerinus, the Second Pyramid of Chephren, the Great Pyramid of Cheops. [© National Geographic Society]



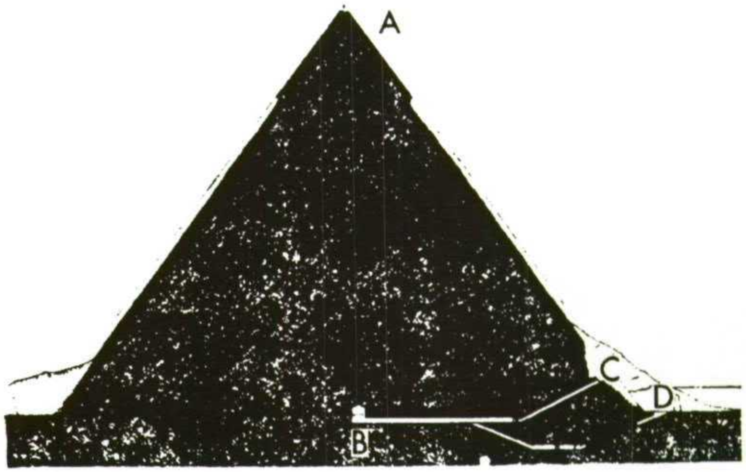
Muon mapping of Chephren's Pyramid

Science, 167, 832 (1970)

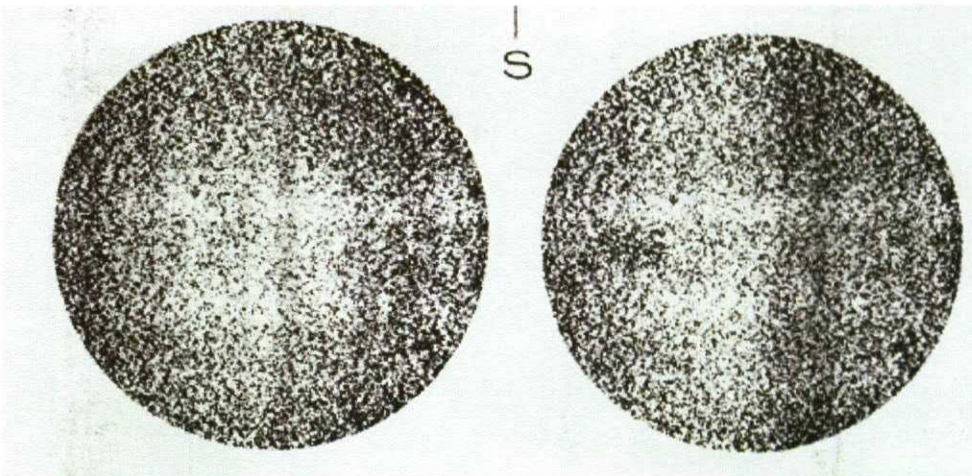
Search for Hidden Chambers in the Pyramids

The structure of the Second Pyramid of Giza is determined by cosmic-ray absorption.

Luis W. Alvarez, Jared A. Anderson, F. El Bedwei, James Burkhard, Ahmed Fakhry, Adib Girgis, Amr Goneid, Fikhry Hassan, Dennis Iverson, Gerald Lynch, Zenab Miligy, Ali Hilmy Moussa, Mohammed-Sharkawi, Lauren Yazolino

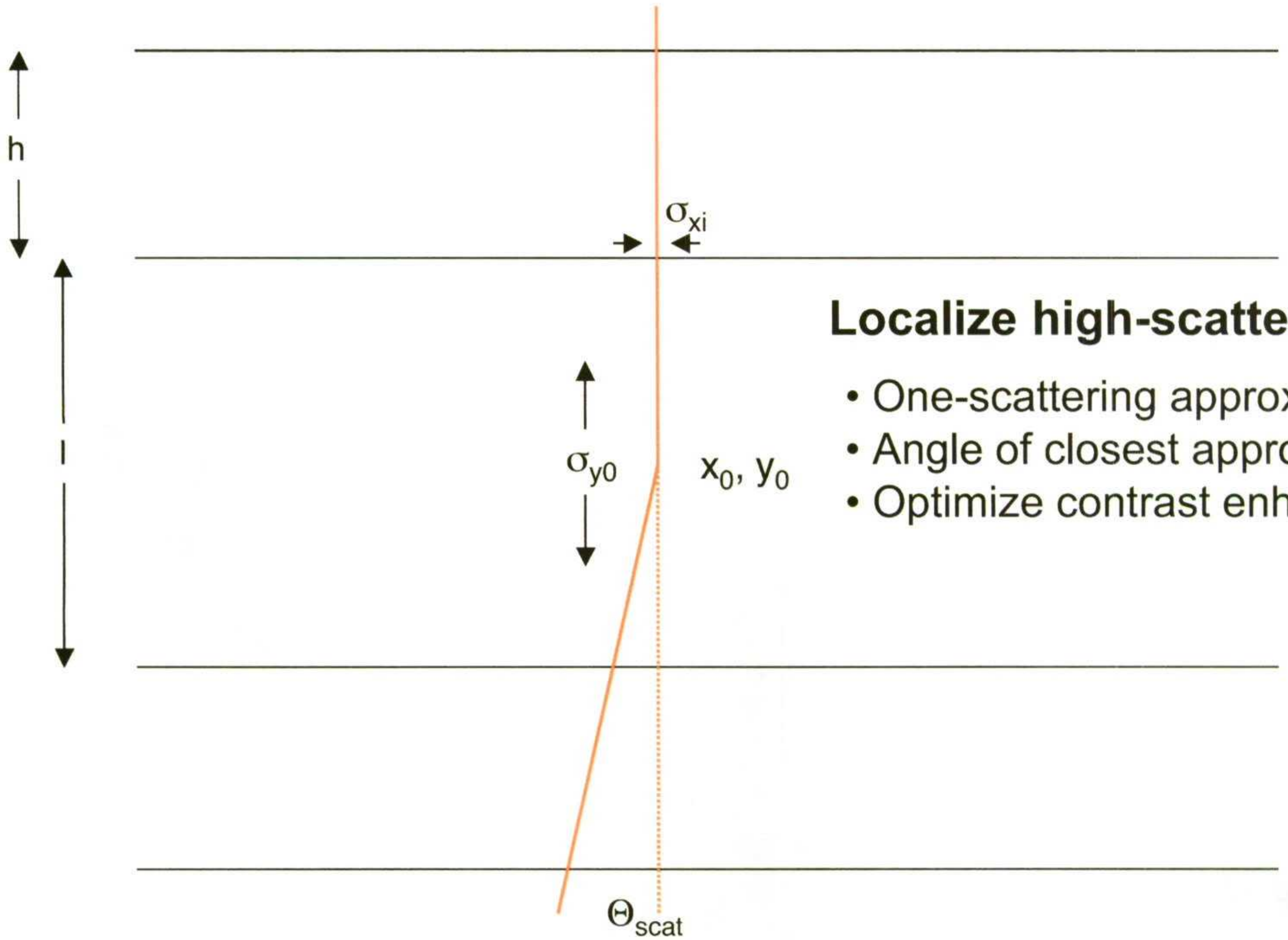


left: **actual image**
right: **simulated image, with hidden chamber as in Cheops**



Only absorption exploited in this analysis – not scattering

Reconstruction via point of closest approach



Localize high-scatterer using:

- One-scattering approximation
- Angle of closest approach of rays
- Optimize contrast enhancement

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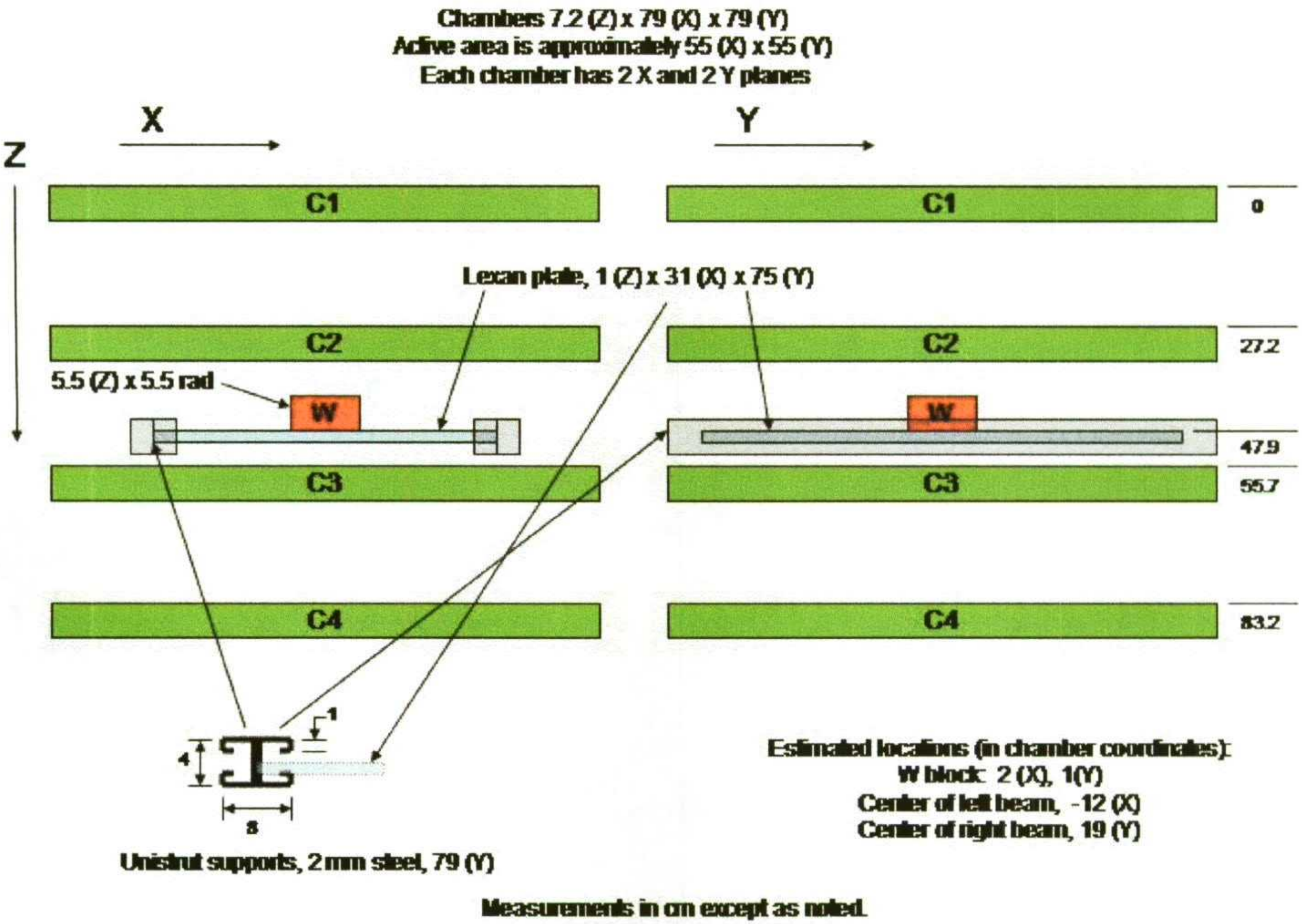
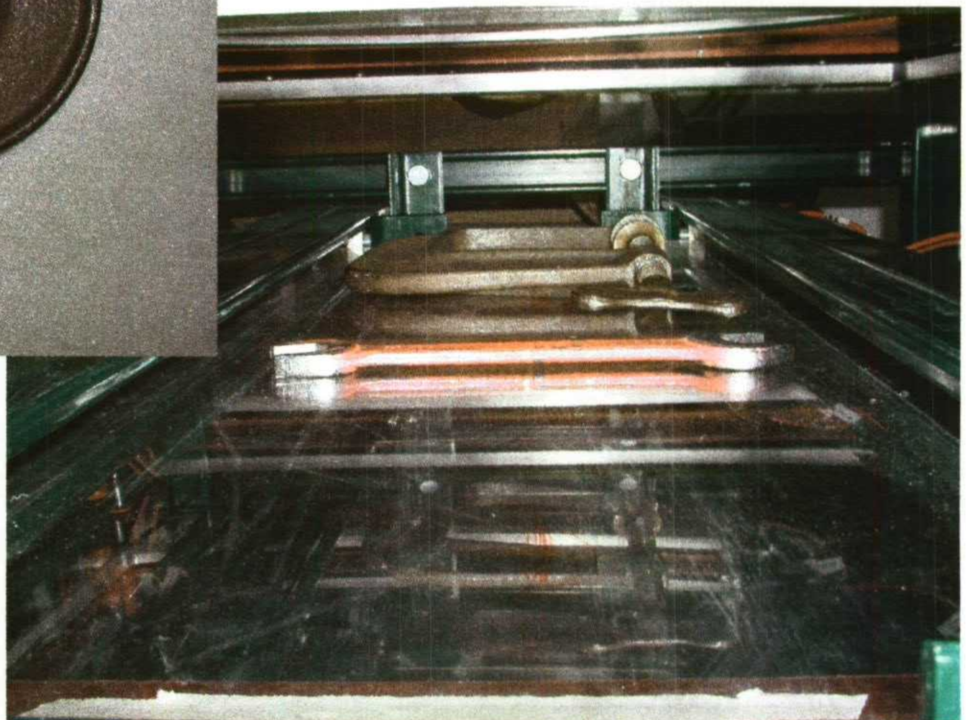
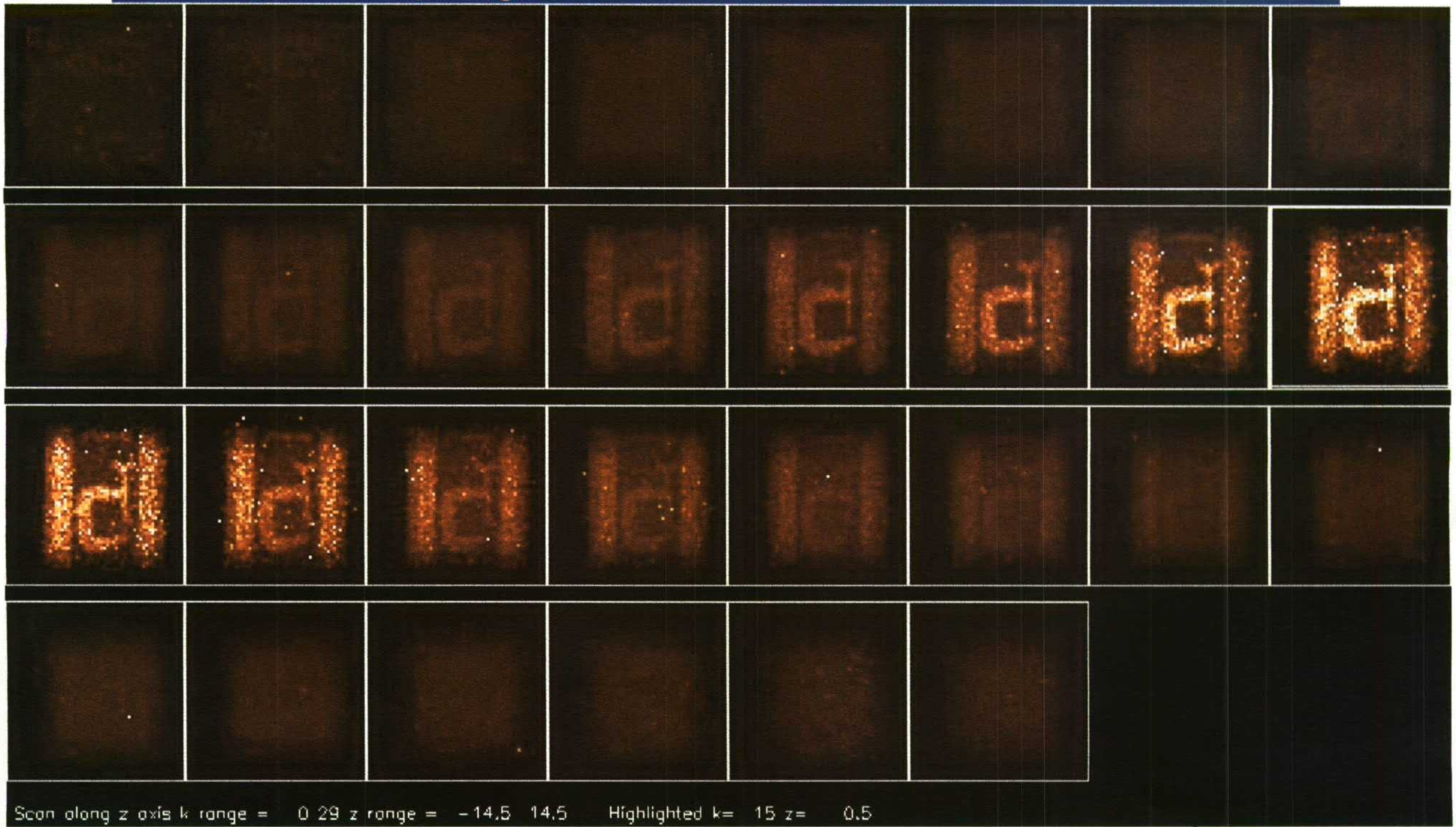
Test object: tungsten cylinder



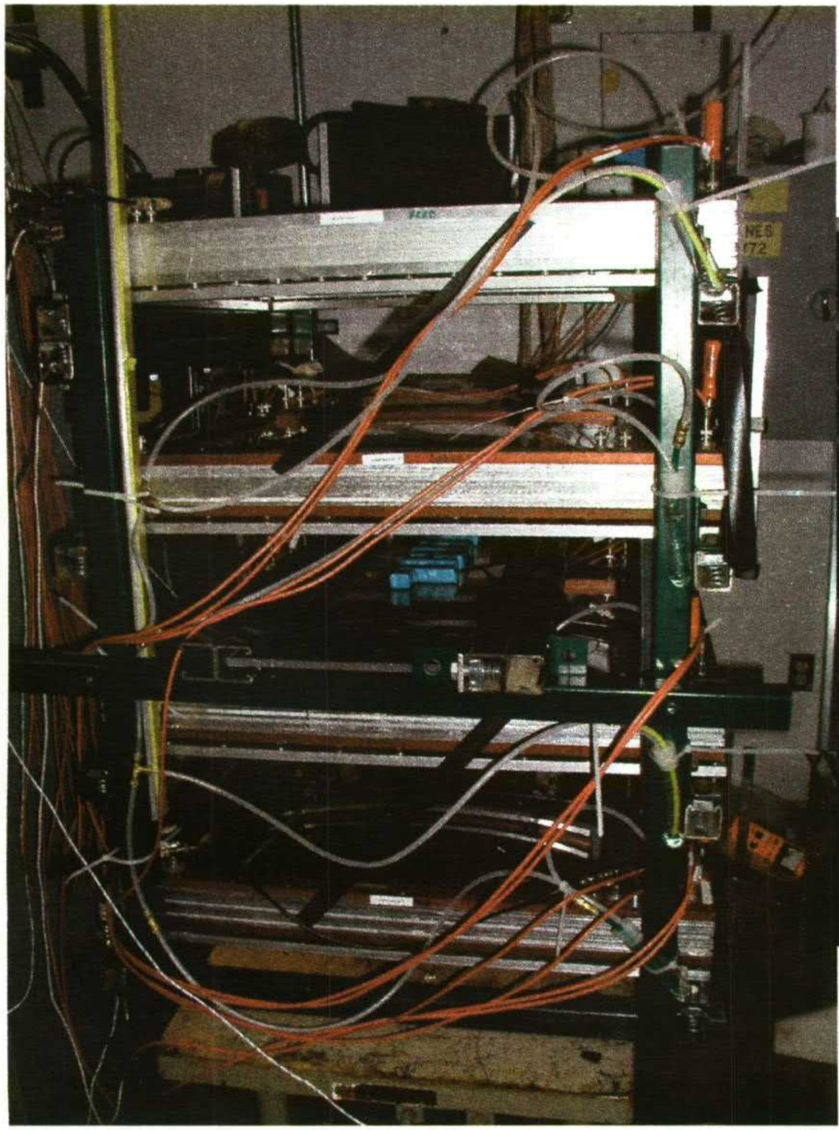
Another object



Clamp in z-projections



One more object



… and its reconstructed slice